South Hadley Wastewater Treatment Plant

Nitrogen Optimization Report

Report produced by:

JJ Environmental, LLC

SOUTH HADLEY WASTEWATER TREATMENT PLANT NITROGEN OPTIMIZATION REPORT

BACKGOUND AND INTRODUCTION

During the early 1980's, Long Island Sound showed significant water quality degradation, mostly in the form of low dissolved oxygen. This resulted in the death of lobsters and a decline in numbers and species of finfish in the southwestern portion of the Sound. Legislators in the States of both New York and Connecticut supported monitoring, research and action plans to preserve and protect the waters of Long Island Sound. Their support resulted in the following:

- In 1985, Congress appropriated funds to both Connecticut and New York to monitor and research water quality.
- The Clean Water Act reauthorization in 1987 established a National Estuaries Program and Long Island Sound was designated an Estuary of National Significance.
- In 1994 the Comprehensive Conservation Management Plan (CCMP) was approved by EPA, New York and Connecticut.

The CCMP was an important document, which identified several problems associated with the degradation of water quality Long Island Sound, including:

- Hypoxia, or low dissolved oxygen (DO)
- Toxic contamination
- Pathogen contamination
- Floatable debris
- Habitat loss and its impact on living marine resources
- Land use and development that degrades habitat and water quality

Of these problems, hypoxia was determined to be the most serious. Hypoxia appears to be caused by large amounts of nitrogen discharged to Long Island Sound by wastewater treatment plants, surface runoff and atmospheric deposition. Nitrogen is typically the limiting nutrient for phytoplankton, a microscopic plant. When phytoplankton dies, it sinks to the bottom waters of the Sound where the decaying phytoplankton uses oxygen in the water column, thus reducing the DO in many cases to less than 2 mg/L (compared to a DO standard of 6 mg/L). The CCMP concluded that the main objective for Long Island Sound corrective actions is to reduce the amount of nitrogen entering the Sound to increase the DO concentrations.

A Long Island Sound total maximum daily load (LIS TMDL) for nitrogen was developed by the States of New York State and Connecticut to protect water quality in the Long Island Sound. Approved by US-EPA, the TMDL specifies a 58.5% reduction in total nitrogen (TN) by 2014. Connecticut proposed to remove about 6056 metric ton (6,670 US tons) per year of TN and New York about 15,570 metric tons (17,150 US tons) per year. Each year beginning in 2000, the waste load allocation for each treatment plant decreases annually each year through 2014.

The LIS TMDL included a provision to re-evaluate and revise the TMDL at a later date. The revision process is currently underway. The revision of the TMDL is being conducted by a workgroup comprised of representatives of the five watershed states (New York, Connecticut, Massachusetts, New Hampshire, and Vermont), EPA, and NEIWPCC. The workgroup is considering many source categories as areas where reductions are possible and evaluating management strategies for achieving those reductions.

As a component of this process, the Upper Basin states (Massachusetts, New Hampshire, and Vermont) study was conducted to assess the feasibility and cost impact of installing low-cost biological nitrogen removal retrofits. This included facilities in the Upper Connecticut River basin in Massachusetts, New Hampshire, and Vermont; as well as facilities in the Housatonic and Thames River basins in Massachusetts.

NITROGEN REMOVAL

Nitrogen enters a wastewater treatment plant in various forms, primarily, ammonia nitrogen and organic nitrogen. A portion of organic nitrogen is hydrolyzed to ammonia nitrogen in the collection system as well as in the wastewater treatment process. The state of the art method for removal of ammonia in wastewater is through biological nitrogen removal (BNR).

BNR is accomplished through two steps; nitrification and denitrification. Nitrification is the conversion of ammonia-nitrogen to nitrite-nitrogen and then to nitrate-nitrogen. This conversion requires aerobic conditions, typically dissolved oxygen concentrations of about 1.5 to 2.0 mg/L. It also uses alkalinity, so the treatment plant must have sufficient alkalinity entering the plant or have the ability to add it otherwise the pH will decrease and result in an inhibition of the nitrification process.

Denitrification is the biological conversion of nitrate to nitrogen gas and requires an anoxic zone with dissolved oxygen concentrations of less than 0.3 mg/L. Denitrification produces alkalinity. The typical BNR process is the Modified Ludzak-Ettinger (MLE) Process shown in Figure 1 and incorporates an anoxic zone followed by aerated zones. The nitrate rich mixed liquor (NRCY) is recycled from the end of the aerated zone to the anoxic zone. Nitrate is converted to nitrogen gas in the anoxic zone and evolves from the liquid into the atmosphere. Activated sludge plants can be modified for BNR by creating an anoxic zone from an existing aerated zone and nitrate recycle.

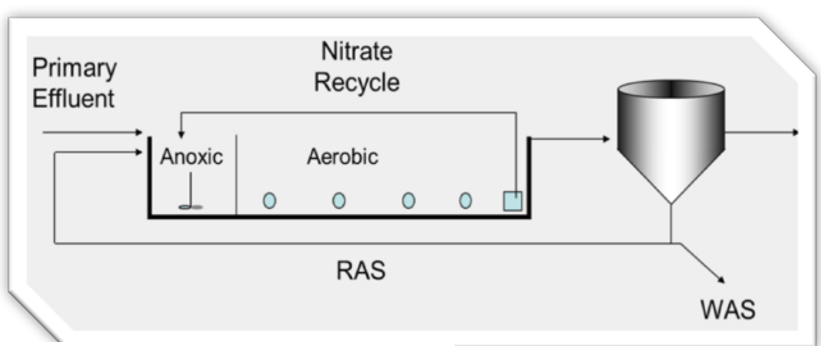

Figure 1 Typical MLE Process

PLANT DESCRIPTION

The South Hadley wastewater treatment plant (Figure 2) is one of 29 facilities included in the "***Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the Upper Long Island Sound Watershed"*** project. The plant is located at 2 James Street, Chicopee, MA and discharges directly to the Connecticut River. It is a 4.2 MGD activated sludge treatment plant with three primary settling tanks, two biological reactor trains with two tanks in each train. Aeration is provided by mechanical aerators on variable frequency drives (VFDs) to allow better control of dissolved oxygen. The flow from the biological system is then conveyed to two secondary clarifiers. The effluent from the secondary clarifiers is disinfected with hypochlorite prior to discharge. Primary and waste activated sludge are thickened in gravity thickeners, dewatered and disposed of off-site.

Figure 2 Aerial View

Currently the plant operates the two primary settling tanks (except during high flows when they place the third tank in service), two of the four biological reactors and both secondary clarifiers. Air is supplied by 50 hp mechanical aerators with variable frequency drives (VFDs). According to plant staff, they have difficulty maintaining sufficient dissolved oxygen concentrations in the reactors. This results in higher effluent ammonia nitrogen concentrations and therefore higher effluent total nitrogen concentrations. In order to optimize nitrogen removal, it will be necessary to further investigate the output of the mechanical aerators and whether they can supply sufficient dissolved oxygen. Investigation should include horsepower output and submergence.

INITIAL EVALUATION

Initially a two-year data set obtained from plant staff was evaluated through a series of statistical analysis and graphing. The staff at this plant is very proactive in obtaining detailed influent and effluent data on various nitrogen species as well as chemical oxygen demand (COD). These data were also available for analysis and were extremely helpful in evaluating current operation and essential in evaluating potential retrofits. South Hadley is the only plant in the study that has this extensive amount of nitrogen data.

Based on the two-year data set, the average daily flow was found to be 2.7 MGD. The plant has significant hydraulic capacity since, based on frequency distribution, 87% of the time the flow is less than 80% of design flow. Influent BOD averaged 164 mg/L and influent TSS averaged 191 mg/L over the two-year period. Influent TKN averaged 32 mg/L and effluent total nitrogen (TN) averaged about 20 mg/L during 2013/2014. The average temperature was 15.2^{o} C. They have some inflow and infiltration problems which result in very high flows during storm events.

An EXCEL desk-top nitrogen removal model was used as a screening tool to determine if the plant had potential for low-cost nitrogen removal. The model showed only limited potential for low-cost nitrogen removal. However recent data has shown some reduction in effluent TN. Based on that information and the fact that this plant discharges directly to Long Island Sound, it was selected for further study (Phase 2) which is based on comprehensive process modeling. The process model software being used for this phase is BioWin.

BIOWIN MODEL

The BioWin model was selected for this project because it is a wastewater treatment process simulator that ties together biological, chemical and physical process models and is used world-wide to design, upgrade, and optimize wastewater treatment plants of all types. It is considered one of the industry standard models.

The modeling process employs two steps. First a baseline model is created and calibrated and then various modifications are made to the baseline model to evaluate which alternatives result in the optimum nitrogen removal. The selected alternative is referred to as the conceptual design model.

The model replicates as closely as possible current plant conditions and is configured to match the number and dimension of the various unit processes. In the case of South Hadley, the model was configured and calibrated using two primary settling tanks, two biological reactors and two secondary clarifiers since that is the normal operation at the treatment facility. The model is then calibrated to confirm that the calculated values match as closely as possible the actual effluent concentrations achieved at the treatment plant. Calibration of the model is one of the most important and critical step in this process.

Average influent concentrations were used for calibration of the model using a steady-state simulation. Model output was compared to average effluent data. The model was considered calibrated if it matched closely with effluent BOD, TSS and total nitrogen. Once the model was calibrated, various design alternatives and changes in process control parameters were evaluated to determine which alternative resulted in the lowest possible effluent total nitrogen. Sensitivity testing was also performed by reducing the temperature to 10^{o} C and increasing the flow to 80% of the design.

It is very important to note that these models assume that the mechanical aerators can deliver the required dissolved oxygen. As stated earlier in this report, there is concern by plant staff that the aerators cannot deliver sufficient DO and therefore a more detailed investigation of their operation is required.

NITROGEN CONCEPTUAL DESIGN

The plant has two trains with two reactors in each train. They currently do not have the ability to use more than two tanks in series. The first model that was configured uses one train only.

Two Tank Model

Currently, the plant operates two of the four aeration tanks. Figure 3a shows the baseline model configuration based on current practice. Using the historic data together with the special sampling, this model was calibrated to match, as closely as possible, actual plant performance. For the conceptual optimization design using only two tanks, the first reactor is anoxic (remove surface aerator and add mixing), the second is aerobic using the existing mechanical surface aerators (Figure 3b). Two variable frequency drive (VFD) nitrate recycle pumps are added and installed in the last aerobic reactor. They are sized at four times the influent flow. Dissolved oxygen, ammonia, pH and nitrate analyzers are also included in this design. There is sufficient alkalinity in the influent so there is no need to provide a system to add alkalinity.

Table 1 Comparison of Baseline to Output from 2-Tank Model

Plant Influent Data			Baseline Model Effluent		2- Tank Design Model Effluent		Comparison of Baseline to 2-tank Design	
Parameters	mg/L	lb/d	mg/L	lb/d	mg/L	lb/d	mg/L	lb/d
Volatile suspended solids	152.49	3385.36	4.96	108.81	3.51	77.1	1.45	31.71
Total suspended solids	191.06	4241.58	6.79	149	4.86	106.58	1.93	42.42
Filtered TKN	29.54	655.87	2.55	55.91	4.38	96.05	-1.83	-40.14
Total Kjeldahl Nitrogen	35	777.02	2.99	65.69	3.42	103.01	-0.43	-37.32
Total Carbonaceous BOD	163.77	3635.78	3	65.75	3.13	68.59	-0.13	-2.84
Total N	35	777.02	19.3	423.65	8.08	177.41	11.22	246.24
Total inorganic N	25.45	564.89	17.02	373.62	5.95	130.58	11.07	243.04
pH	7.36	0	7.12	0	7.42	0		
Ammonia N	25.45	564.89	0.71	15.65	2.56	56.18	-1.85	-40.53
Nitrate N	0	0	14.41	316.21	0.19	4.28	14.22	311.93

The output from the model, at an average temperature of 15^{o} C as compared to the baseline (existing plant) model, is shown in Table 1 and indicates a significant improvement in nitrogen removal. This model requires a minimum of 3 mg/L dissolved oxygen in Bioreactor 1.

Currently, influent TN averages about 777 lb/d and the plant discharges about 424 lbs/d resulting in a removal of approximately 353 lbs/d (777 lbs/d-424 lbs/d). With the two-tank configuration, the model is predicting that the plant would discharge 177 lbs/d total nitrogen

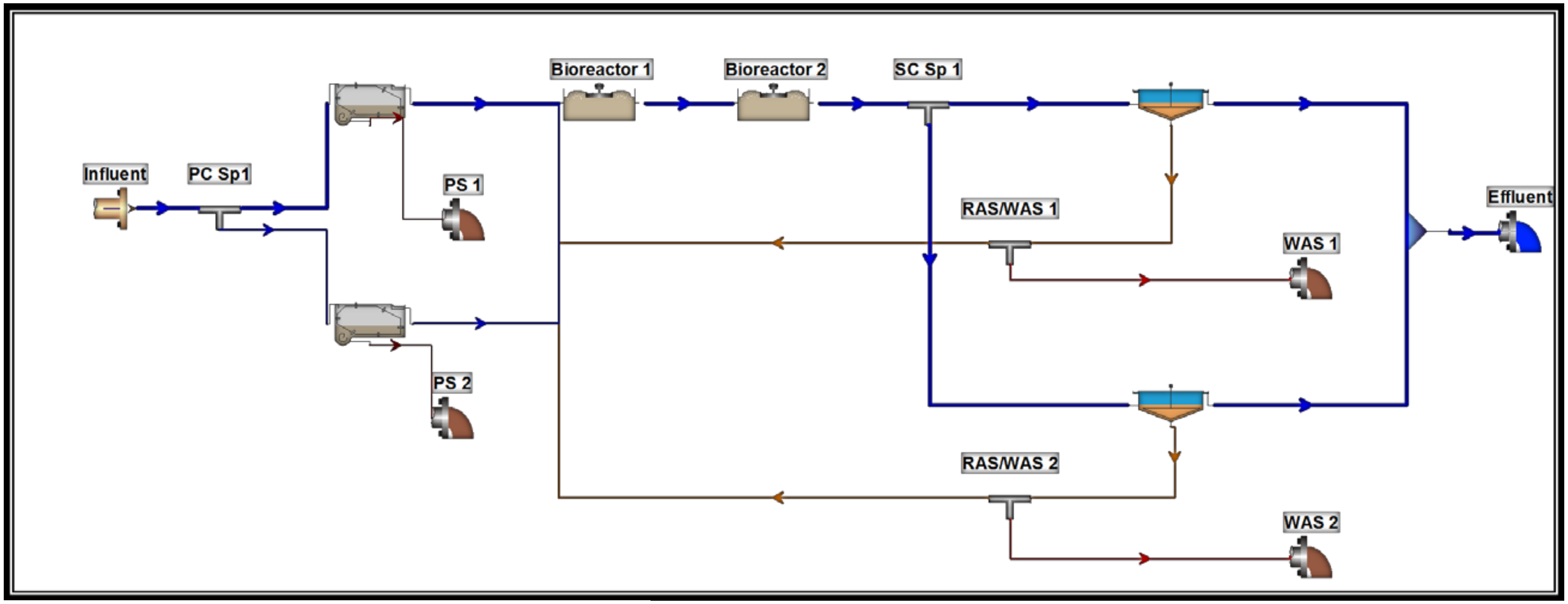

Figure 3a South Hadley Baseline Model

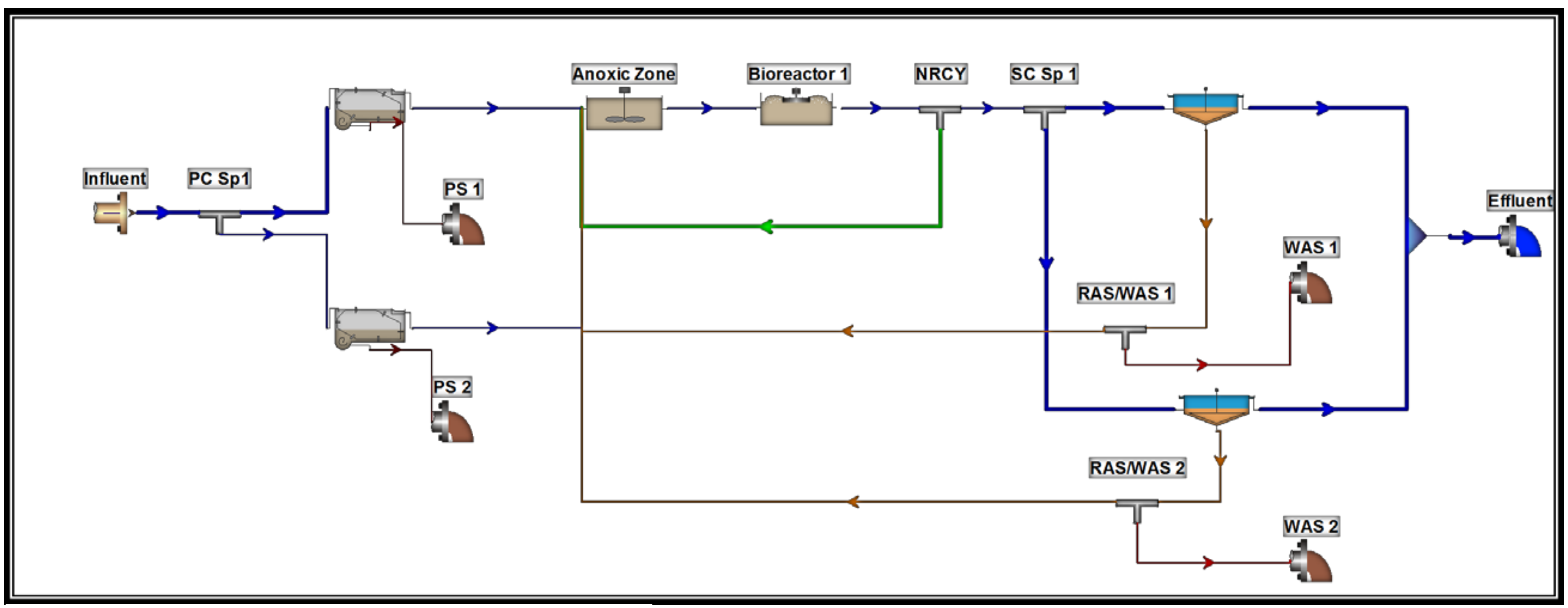

Figure 3b South Hadley Conceptual Design Model

with a concentration of 8.08 mg/L resulting in a removal of 600 lbs/d (777 lbs/d-177 lbs/d). The increase removal over current performance is 246 lbs/d total nitrogen or about 90,000 lbs/year.

The model was then simulated at 10^{o} C and the flow was increased to 80% of design. The purpose of this model is to stress the system and evaluate performance. It was found that there is insufficient capacity to completely nitrify, and most of the nitrogen is in the form of ammonia with effluent ammonia concentrations of 25 mg/L. Therefore, another model configuration was designed and simulated.

Four Tank Models

Two models were designed and simulated. A two train two tank model operating in parallel was configured (Parallel Configuration), along with a single train consisting of four tanks in series (Series Configuration). In the parallel configuration the first tank in both trains is anoxic followed by an aerobic selector. In the 4 tank in line series model the first two tanks are anoxic followed by two aerobic selectors respectively. (Figure 4a and 4b). Again, these models require sufficient DO in the aerated reactors so the output from the existing mechanical aerators must be evaluated.

Parallel Configuration: For the parallel configuration, the first reactor in each train is anoxic and retrofit with mixers, the second is aerobic using the existing mechanical aerators. Two variable frequency drive (VFD) nitrate recycle pumps are added and installed in the last aerobic reactor. The pumps are sized at four times the influent flow. Dissolved oxygen, ammonia, pH and nitrate analyzers are also included in this design. Table 2 shows the output from this model as compared to the baseline.

Table 2 Comparison of Baseline to Output from 4-Tank Parallel Design Model

Plant Influent Data			Baseline Model Effluent		4-Tank Parallel Design Model Effluent		Comparison of Baseline to 4-tank ParallelDesign	
Parameters	mg/L	lb/d	mg/L	lb/d	mg/L	lb/d	mg/L	lb/d
Volatile suspended solids	152.49	3385.36	4.96	108.81	3.79	83.42	**1.17**	**25.39**
Total suspended solids	191.06	4241.58	6.79	149	5.45	120.09	**1.34**	**28.91**
Filtered TKN	29.54	655.87	2.55	55.91	2.45	54.01	**0.1**	**1.9**
Total Kjeldahl Nitrogen	35	777.02	2.99	65.69	2.78	61.3	**0.21**	**4.39**
Total Carbonaceous BOD	163.77	3635.78	3	65.75	2.23	49.11	**0.77**	**16.64**
Total N	35	777.02	19.3	423.65	8.65	190.63	**10.65**	**233.02**
Total inorganic N	25.45	564.89	17.02	373.62	6.55	144.17	**10.47**	**229.45**
pH	7.36	0	7.12	0	7.41	0		
Ammonia N	25.45	564.89	0.71	15.65	0.67	14.85	**0.04**	**0.8**
Nitrate N	0	0	14.41	316.21	5.67	124.98	**8.74**	**191.23**

Currently, influent TN average about 777 lb/d and the plant discharges about 424 lbs/d resulting in a removal of about 353 lbs/d (777 lbs/d-424 lbs/d). With the two-train, two-tank parallel configuration, the model is predicting that the plant would discharge 191 lbs/d total nitrogen with a concentration of 8.65 mg/L resulting in a removal of 586 lbs/d (777 lbs/d-191 lbs/d). The increase removal is 233 lbs/d total nitrogen or about 85,000 lbs/year.

Although somewhat less nitrogen is removed with this configuration at average conditions, it is less sensitive to temperature and increased flow as compared to the 2-tank configuration. At 10^0 C and 80% of design flow, effluent TN concentration would increase to 8.85 mg/L and total nitrogen removed would decrease to about 64,000 lbs/year.

Series Configuration: Since the plant does not have the ability to operate four tanks in series, some minor tank modification would have to be made to create the desired flow. The flow would travel from Reactor 2 to 1 to 3 and finally to 4 (existing plant names). Openings would be created to all water to flow from one tank to the next and gates would be installed on these openings. The first reactor (Reactor 2) and the second reactor (Reactor 1) would be dedicated anoxic zones. The mechanical aerators would be removed and replaced with mixers. Two variable frequency drive (VFD) nitrate recycle pumps are added and installed in the last aerobic reactor and will be sized for four times the influent flow. Dissolved oxygen, ammonia, pH and nitrate analyzers are also included in this design. Table 3 shows the output from this model as compared to the baseline model.

Table 3 Comparison of Baseline to Output from 4-Tank Series Design Model

Plant Influent Data			Baseline Model Effluent		4- Tank Design Model Effluent		Comparison of Baseline to 4-tank Design	
Parameters	mg/L	lb/d	mg/L	lb/d	mg/L	lb/d	mg/L	lb/d
Volatile suspended solids	152.49	3385.36	4.96	108.81	4.26	93.85	**0.7**	**14.96**
Total suspended solids	191.06	4241.58	6.79	149	6.13	135.21	**0.66**	**13.79**
Filtered TKN	29.54	655.87	2.55	55.91	2.37	52.19	**0.18**	**3.72**
Total Kjeldahl Nitrogen	35	777.02	2.99	65.69	2.74	60.39	**0.25**	**5.3**
Total Carbonaceous BOD	163.77	3635.78	3	65.75	2.29	50.41	**0.71**	**15.34**
Total N	35	777.02	19.3	423.65	6.35	140.05	**12.95**	**283.6**
Total inorganic N	25.45	564.89	17.02	373.62	4.25	93.68	**12.77**	**279.94**
pH	7.36	0	7.12	0	7.28	7.41		
Ammonia N	25.45	564.89	0.71	15.65	0.64	14.02	**0.07**	**1.63**
Nitrate N	0	0	14.41	316.21	1.84	40.67	**12.57**	**275.54**

With the four-tank series configuration, the model is calculating that the plant would discharge 140 lbs/d total nitrogen with a concentration of 6.35 mg/L resulting in a removal of 637 lbs/d (777 lbs/d-140 lbs/d). The increased removal is 283.6 lbs/d (637-424 lbs/d) total nitrogen or about 103,500 lbs/year. At 10^0 C and 80% of design flow, effluent TN concentration would increase to 8 mg/L and total nitrogen removed would decrease to about 73,200 lbs/year.

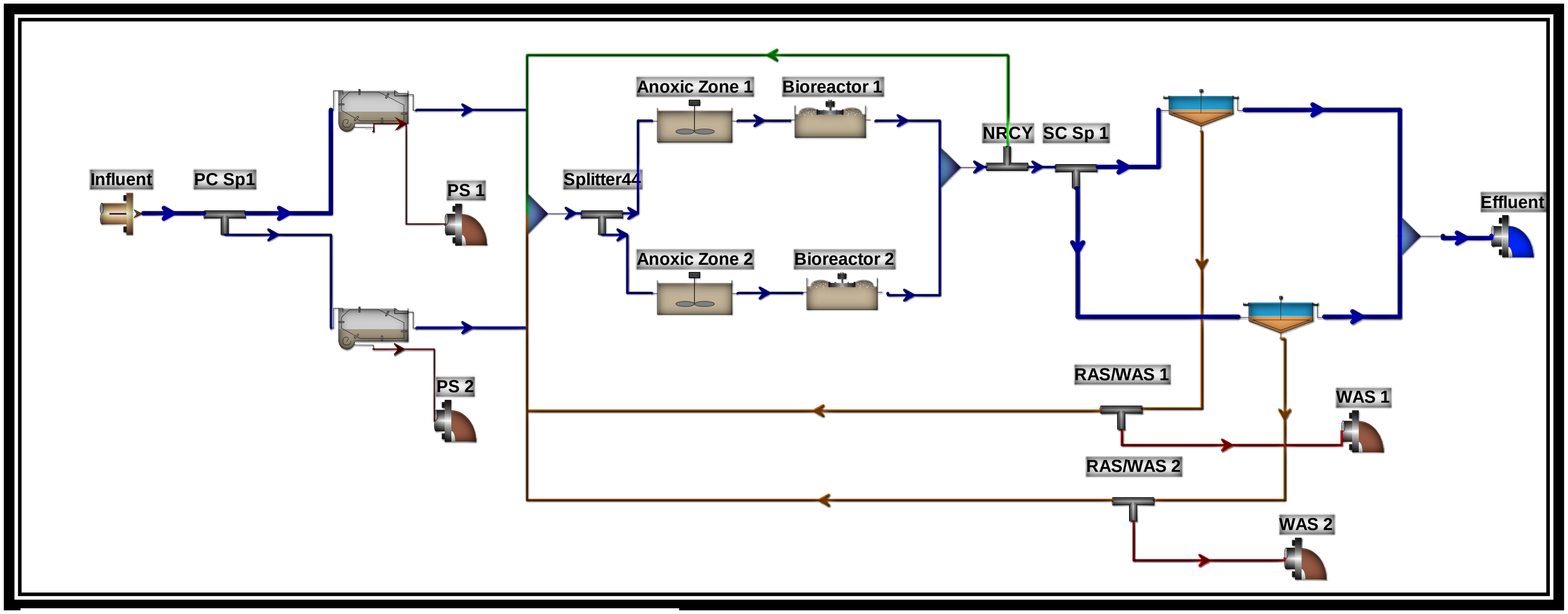

Figure 4a South Hadley 4-Tank Parallel Process

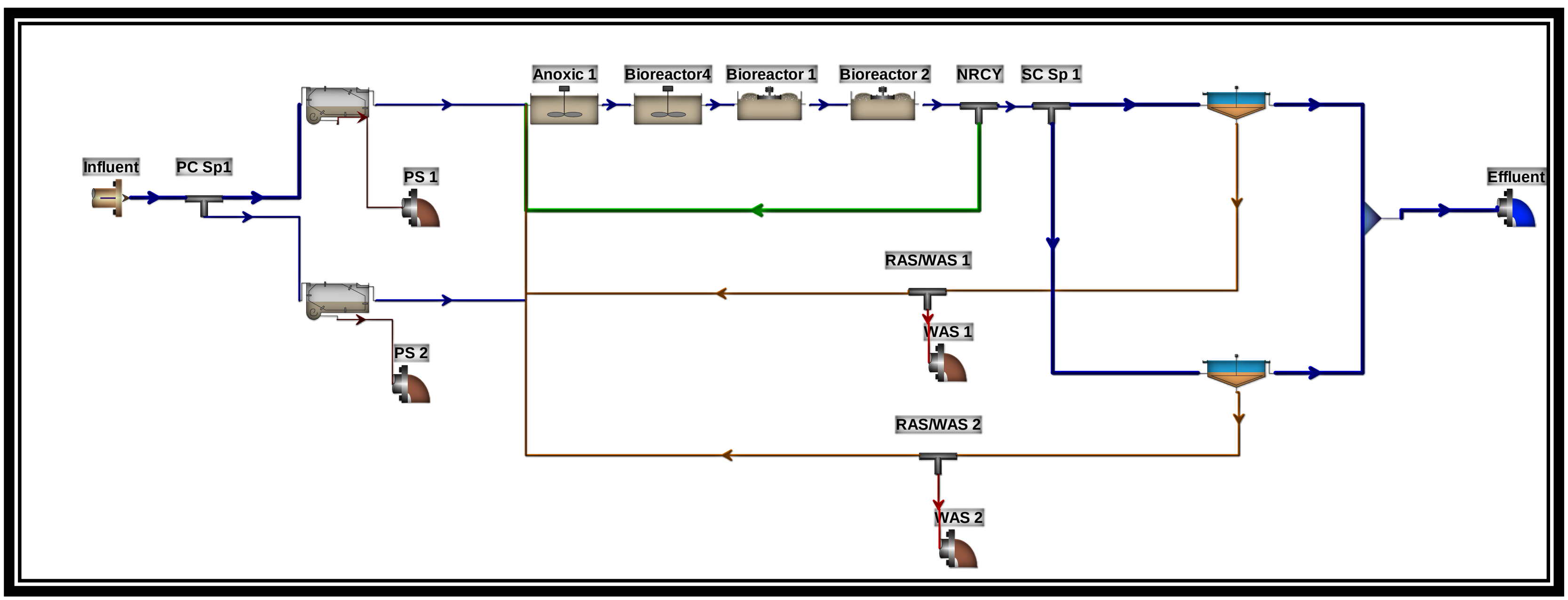

Figure 4b South Hadley 4-Tank Series Process

This model gives flexibility to the operator. The plant can be operated in series, with one parallel train or with two parallel trains. Therefore, based on the model prediction and the increased operator flexibility, the recommendation would be to convert the four existing reactors to an in- series operation. More operator flexibility can be achieved by changing the second anoxic zone to a swing zone using a mixer aerator but this would add between $100,000 and $150,000 to the cost.

NEIWPCC

Low Cost Retrofits for Nitrogen Removal at Wastewater Treatment Plants in the upper Long Island Sound Watershed

COST ESTIMATE

South Hadley Rev 2

Contractor Name:	JJ Environmental	Date:	13-Aug-14
Address:	17 Archer Lane	Project No.	0302-001
	Darien, Ct 06820	Proposal No.	20
Telephone No:	1-203-309-8768		

		Revisions
SECTION A: CONTRACTOR WORK		
1. Total Contractor Labor	$84,538.91	
2. Total Contractor Material	$113,200.00	
3. Total Contractor Equipment	$36,131.00	
4. Unit Price Costs		
5. Subtotal Contractor Cost	$233,869.91	
6. Contractor Mark-Up 15%	$35,080.49	
7. Contractor Total Section A	$268,950.40	
SECTION B: CONTRACTOR WORK		
8. Names Of Subcontractors		
A. Electrical Subcontractor	$88,945.70	
B. Instrumentation Integrator	$8,510.00	
C.		
D.		
E.		
F.		
9. Total Subcontractor's Proposals (A through F)	$97,455.70	
10. Contractor's Mark-Up On Subs Proposals (5%)	$4,872.79	
11. Subcontractor Total Section B	$102,328.49	
SECTION C: TOTAL CONTRACTED UNIT PRICE COSTS		
SECTION D: CONTRACTOR'S REQUEST		
12. Amount Requested (Total Lines 7 & 11)	**$371,278.88**	

Figure 5 Cost Summary

COST ESTIMATE

A preliminary construction cost estimate was prepared based upon the two-train, two-tank parallel concept and the four-tank in-series conceptual design. A cost per pound value calculation was made using the construction cost and the net nitrogen removed increase from current operation. The estimate includes the cost of all equipment (mixers and pumps, piping, instrumentation and installation (Figure 5). The total cost for the in-line series design concept is estimated to be approximately $371,000.00. Labor rates have been calculated using U.S. prevailing wage rates for the State of Connecticut. There does not appear to be any increased costs of plant operating labor. In both of the conceptual model configuration, two mechanical aerators will be taken out of service, so there should not be any additional electrical costs and there might be a slight savings since the combination of the mixers and pump horsepower should be a lower than the mechanical aerators. It is recommended to have a service contract for the instruments so this will be an added cost. The value of these contracts varies considerably depending on the number of instruments to be serviced, the frequency of service and the level of service.

COST PER POUND OF NITROGEN REMOVED

Normalizing the retrofit costs as cost per pound of nitrogen removal is a way of helping communities and regulatory agencies make the decision of whether or not to retrofit the plant for nitrogen removal. For South Hadley, the model is predicting that the plant will remove an additional 283.6 lbs/d of nitrogen or lbs on an annual basis over baseline conditions.

Table 4 Cost Example-15 years, 6%

Additional Nitrogen Removed & Cost Evaluation	
Delta Pounds N Removed Per day	283.6
Pounds Annually	103,514
Pounds over 5 years	517,570
Pounds over 15 years	1,552,710
Cost of Improvement	$ 371,278.88
Cost Per Pound Over 1 Year	$ 3.59
Cost Per Pound Over 15 Years	$ 0.24
Calculate Cost Per Pound Over 15 Years Including Interest	
Interest Rate	6%
Term in Years	15
Monthly Payments 100% Financed	$ 3,133.06
Cost Principle & Interest	$ 563,950.80
Maintenance & Services $3,000.00 Annualy	$ 45,000.00
Total Cost Over 15 Years	$ 608,950.80
Cost Per Pound Over Of Over 15 Years	**$ 0.39**

In evaluating the cost per pound of nitrogen removed, there is a significant dependence on the cost of money and the borrowing period. Table 4 shows an example using a term of 15 years at an interest rate of 6%. The example shows a cost of $0.39 per pound of nitrogen removal under the specified terms.

SUMMARY

Based on the information from plant staff and BioWin model predictions, it appears that nitrogen removal efficiency at South Hadley can be improved by creating a dedicated anoxic zone and adding internal nitrate recycle. The model predicts that 103,500 lbs of TN per year can be removed at <u>average temperature, flows and loads</u> and the plant can achieve good nitrogen removal even at low temperatures and up to 80% of design flow. However, this assumes that sufficient dissolved oxygen can be applied by the mechanical aerators. If the cost is of these improvements are amortized over 15 years at 6% interest, then the cost is $0.39 per pound of nitrogen removed.